Sand Ripple Generation, Evolution and Decay: An Investigation of Physical and Biological Controls

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LONG-TERM GOALS

The central goal of this research is a deeper understanding of bed state adjustment in mobile sandy sediments on the inner continental shelf, in particular the adjustment due the combined effects of variable fluid forcing and biological reworking of the sediment surface. The work is motivated by the lack of suitable observational basis for developing and testing models of seabed roughness evolution through fluid-sediment-biological interactions in sandy inner shelf environments.

OBJECTIVES

Our primary objective in this first phase of the project is to quantify the rates of ripple and seabed roughness degradation arising from biological activity on and within the seafloor. The second objective is to compare the measured degradation rates to those predicted by analytic and numerical models of bed roughness change by biological organisms.

APPROACH

As part of the SAX04 experiment, instrumented pods were deployed at the SAX04 site off Fort Walton Beach, and cabled to the *R/V Seward Johnson*. The bottom pod sensors included single-point velocimeters, an upward-looking acoustic Doppler current profiler (ADCP), downward-looking coherent Doppler profilers, rotary imaging sonars, and laser-video bed profiling systems. This suite of sensors provided measurements of the surface-to-bottom current profile, the wave directional spectrum, bottom stress and bottom boundary layer turbulence, ripple geometry, and the bed roughness

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spectrum. In addition to monitoring naturally-occurring changes in bed roughness, SCUBA divers carried out manipulative experiments at the pod locations, introducing both artificial ripples (by raking) and colored sediments in specified initial patterns. These manipulative experiments allowed us to observe the time scales of bottom roughness decay as a function of the spatial scale of the initial disturbance, at times when the physical forcing mechanisms were weak. Finally, we will be comparing these observations of the decay of the ripple spectrum to the predictions of biological seabed disturbance models. The primary focus of the modeling component of the project is a numerical automaton bioturbation model, developed for studies of mixing processes in surficial seafloor sediments.

WORK COMPLETED

Funding for the project began in June 2004. During June-July-August, the two instrument pods Dalpod 1 and Dalpod 2 were constructed and tested at Dalhousie. The pods and associated instrumentation and hardware were shipped to the Naval Surface Warfare Center-Panama City (NSWC-PC), arriving on schedule on September 13. Mounting the sensors on the pods began that same day. This activity was interrupted when the NSWC-PC was closed at mid-day on September 14 because of the impending arrival of Hurricane Ivan, and resumed when the NSWC-PC reopened on September 17. The pods were loaded on *R/V Pelican* on September 20, and deployed at the SAX04 site on September 21, one day ahead of schedule. We returned to NSWC-PC aboard *R/V Pelican* on September 24, loaded and set up our data acquisition equipment on *R/V Seward Johnson* in the research van on the foredeck. The *R/V Seward Johnson* attached to the 4-point moor on September 25. Because of the possibility of high seas and winds from Hurricane Jeanne, it was decided not to deploy our cables. The ship left the mooring later that day, steaming west toward Mobile to wait out Hurricane Jeanne, and returned to the mooring on the morning of September 28. With assistance from the NRL divers, our cables were connected to the pods by midday on the 28th. With one exception (the ADCP), all sensors and underwater nodes came online. The remainder of September 28 and 29 was devoted to sorting out the problem with the ADCP (it had to be recovered, reset and redeployed), and setting up the data acquisition configurations for the different instruments. Routine data collection began on September 30th and, except for intervals when the ship had to leave the mooring because of weather, continued until the final day of the experiment on November 1. The weather events which forced disconnection from the mooring were Tropical Storm Matthew (October 8-11), and a brief unnamed storm on October 14-15. We are pleased to report that no sensors failed during the experiment and that approximately 25 Gbytes of data were acquired, not including the roughly 30 tapes of time-lapse video imagery.

Because we did not connect to the mooring until 10 days after the passage of Hurricane Ivan, the ripples which formed during Ivan had already aged considerably. In contrast, we returned to the site immediately after Tropical Storm Mathew, so Mathew's ripples were quite fresh initially. Further, except for the weather event on October 14-15, the physical forcing at the seabed remained relatively weak for the remainder of the experiment. Thus, we were able to monitor the degradation of Mathew's ripples over the 20-day period immediately following the storm event, during which time physical effects on the ripple field were likely to have been small relative to biological degradation mechanisms. In addition, visibility in the bottom boundary layer was much better after Mathew than Ivan. While the turbid conditions did not affect the acoustic systems, light scattering from the suspended particulates did reduce the effectiveness of the laser bed profiling system, and the video observations of bed disturbance by biological organisms. We are therefore focussing primarily upon the ripples from Mathew.

Several bed manipulation experiments were carried out. These included at least two repetitions each of artificial ripples with 3, 4, 6 and 8 cm primary wavelengths, and three experiments with mounds of 0.5 mm mean diameter glass beads. In addition, cores were collected relative to ripple crests and the glass bead mounds, and 5 bulk sediment samples were collected and screened for identification and analysis of infauna.

RESULTS

The spatial structure of Mathew's ripples when we returned to the site is illustrated by the acoustic fanbeam image in Figure 1a. Ripple wavelengths were about 50 cm. The high contrast between dark and light areas indicates that the ripples were sharp-crested. More than 14 days later, these features were much less distinct (Figure 1b).

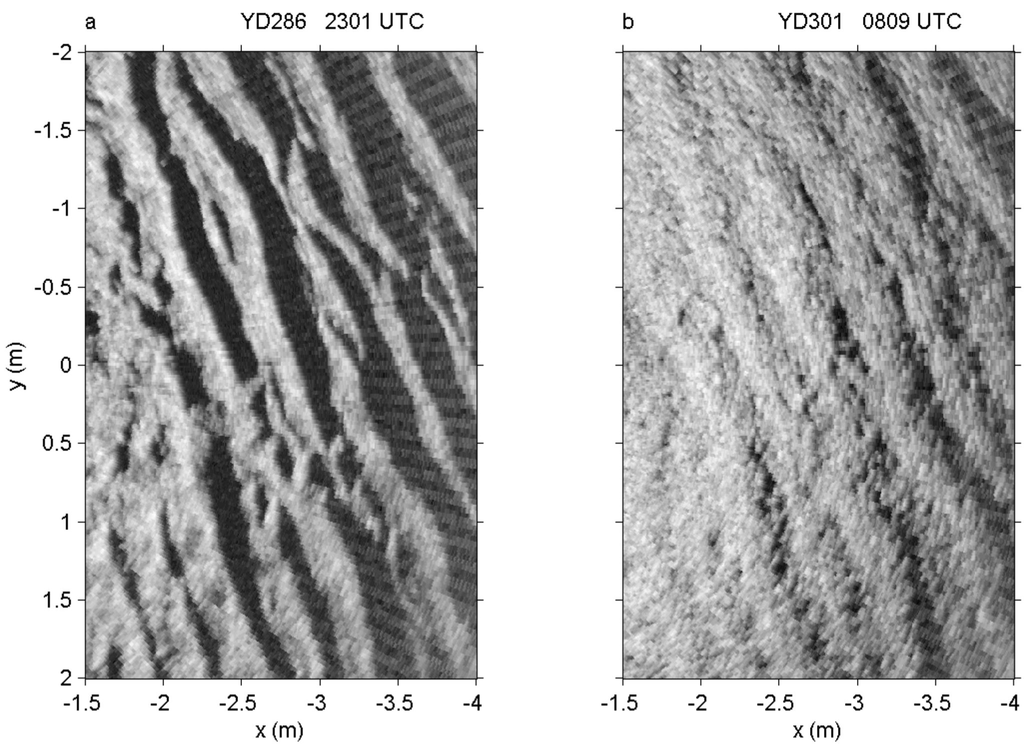

Figure 1: Two acoustic images of the seabed at Dalpod 1: (a) 1 d after Tropical Storm Mathew and (b) about 14.3 d later. The images were acquired with a 2.25 MHz rotary sonar centered at the xy coordinate origin: i.e. to the left of each image. Ripple troughs are thus more in acoustic shadow (darker shades of grey) with increasing distance to the right. Note the 0.5-m wavelength ripples prominent in (a), and highly degraded in (b).

Figure 2 shows the time evolution of the bed elevation spectrum over 19 days after Mathew, including the period spanned by the 2 images in Figure 1. The gradual decrease in the peak spectral density at 2 cpm is evident, as is the loss of energy at the first harmonic, 4 cpm, in the first several days. The rapid disappearance of 1st harmonic energy is consistent with the ripples becoming less sharp-crested with time. (The gap in the record is due to the vessel leaving the mooring on October 14-15.)

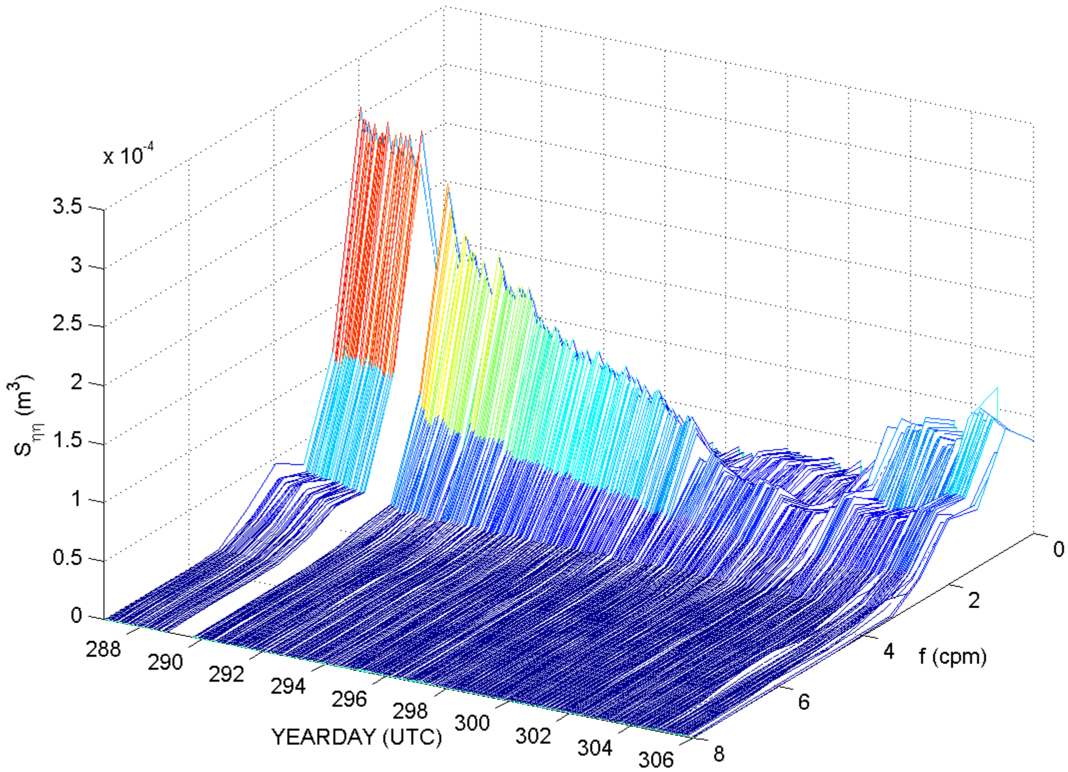

Figure 2: Bed elevation spectra for the 19-d period following Tropical Storm Mathew. Data from 2.25 MHz rotary sonar profiles of the seabed at Dalpod 1. Note the gradual decay over 2 weeks of the primary ripple peak at 2 cpm.

The results in Figures 1 and 2 illustrate the observed rates of ripple degradation at this site for a period in which, as previously mentioned, physical mechanisms sufficiently energetic to influence the local sediment dynamics were for the most part either weak or absent. The implication is that the observed rates of decay as a function of spatial frequency are largely the result of biological activity, an implication which is supported by the video imagery.

IMPACT/APPLICATIONS

This project is directly relevant to questions related to sound scattering from and penetration into sandy marine sediments, and to the arguably broader question of the predictability of ripple geometry on the inner continental shelf. Both questions arise in relation to buried object detection, in relation to the rates of burial or exposure of objects on the seafloor, in relation to temporal and spatial variability in seafloor acoustic scattering, and in relation to predicting the physical conditions (wave heights, currents, etc.) on the inner shelf area at a given time: all “needs-to-know” for naval operations in coastal environments.

PUBLICATIONS

Hay, A. E. and T. Mudge, 2004. Principal bed states during SandyDuck97: Occurrence, spectral anisotropy, and the bed state storm cycle, *J. Geophys. Res.*, in press.